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A 2008-2012 PROGRAM FOR HTS MAGNET R&D AT FNAL

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Abstract - For the development at FNAL of superconducting (SC) accelerator magnets above 20 T for future muon colliders and storage rings, the following High Temperature Superconductor (HTS) magnet development program is proposed. This program is intended to be conducted in close collaboration with U.S. National Labs, Universities and Industry, similarly to the present Nb_3Sn magnet and conductor R&D programs. The expected duration of this plan is 4 years.

Introduction

The main application of HTS magnets at Fermilab is presently in the realm of Muon Colliders, which require high field solenoids (>20 T) for muon beam cooling. This includes the high field sections of a 6D Helical Cooling Channel [1, 2], and high-field solenoids (> 30 T) for the final, low emittance stage of the muon cooling channel [3-5]. The robust and versatile infrastructure that was developed in TD in support of advanced superconductor and accelerator magnet development, together with the expertise acquired by the magnet scientists and engineers of the Magnet Systems Department in the Nb_3Sn and Nb_3Al technologies, makes TD an ideal setting for exploring magnets made of HTS materials.

General Magnet R&D steps

The first step of magnet R&D is to prepare with the accelerator designers a set of functional specifications that include minimum needed aperture, magnet or section length, field components and quality, end field quality, alignment tolerances, and cryogenic and power requirements.

The second step is that of conceptual design studies of coils that meet the agreed specifications on the magnetic, mechanical, cryogenic, power needs and quench protection aspects of the HTS and possibly also hybrid coils. This step goes hand in hand with the superconductor properties and will evolve and change along with any superconductor progress done in the meantime. For this reason, it is crucial to pursue an assertive conductor R&D program in parallel to the magnet development work. Solenoidal configurations offer a welcomed freedom in the choice of the conductors including HTS round wires and tapes as well as HTS cables. The SC R&D will monitor the best performing HTS's on the market and develop the appropriate conductor (cable) technologies suitable for the magnets.

The third step of the magnet R&D includes building and testing HTS and hybrid models for both the Helical Cooling Channel and the High Field Solenoids. The goal of this phase is to develop and demonstrate HTS coil technology and performance, and study the magnetic, mechanical, thermal and quench properties of the HTS coils being fabricated.

The HTS coil and conductor R&D programs are detailed in the following sections.

HTS Coil Program

State-of-the-art HTS materials of sufficient quantity are needed to start out the program. This includes Bi-2212 round wire, Bi-2223 and YBCO tapes. The first phase of the coil program will be based on tapes, which are high performing and do not require reaction. Focus will be on single and multi-layer pancake coils with outer diameter smaller than 77 mm to be tested in the 14T/16T Teslatron solenoid. A series of coils of increasing sizes will be designed and tested to gradually increase the magnetic field. YBCO is the best candidate for high field solenoids based on its high critical tensile stress, which is more than double that of Bi-2223, and an order of magnitude larger than Bi-2212. The conductors will be chosen based on comprehensive characterization. To start work, a hermetic Bi-2223 tape will be used to commission winding, instrumentation and testing of coils due to its excellent performance reproducibility under thermal cycling. Then coil winding will be reproduced using the more expensive YBCO tape produced by SuperPower, which has the best properties including I_c, anisotropy and lengths. With this tape the record field of 26.8 T was reached last year at FSU in a pancake coil made by the company.

In parallel with the work on tapes, work on round Bi-2212 wire and cable will be performed in cooperation with the HTS National Collaboration. Bi-2212 wire requires high temperature processing in oxygen. Ovens will be retrofitted with special ceramic retorts and control systems for the oxygen atmosphere, and commissioned in compliance with the appropriate safety rules.

Phase-I will include the following activities:

- Magnetic and mechanical analysis and design of single and double layer pancake coils;
- Calculation of magnetic and mechanical coupling of Teslatron and model coils;
- Design of winding tooling and development of efficient coil winding procedure;
- Design, fabrication and commissioning of testing setup;
- Implementation of instrumentation (voltage taps, spot heaters, strain gauge, thermometers, etc.) and data analysis;
- Design of quench protection system and calculation of cooling requirements;
- Fabrication and test of model coils of different sizes, conductors and mechanical structures, coil stabilization and cooling conditions;
- Study of coil performance at self-field and external field; training, training memory, temperature and ramp rate sensitivity; stresses in coil and support structure; quench origin, development and propagation.

For Bi-2212 coils the following additional activities will be required:

- Study of React&Wind vs. Wind&React technology;
- Study of allowed coil winding tension;
- Study of insulation;
- Heat treatment optimization;
- Study of coil impregnation;
- Coil preload and stress management optimization.

In Phase-II of the coil program, larger multi-section HTS coils will be fabricated and tested to achieve higher magnetic fields and force levels. A special cryostat with several independent power leads will be designed and procured.

HTS Conductor R&D

Coherently with monitoring the best performing HTS's on the market, state-of-the-art YBCO and Bi-2223 tapes, and Bi-2212 round wire and cables will be studied and used in support of the coil program. The Superconducting R&D laboratory has two solenoids (Teslatrons), capable of producing fields up to 15 T in a 4.2 K helium dewar. Anti-cryostats allow testing in an ample range of temperatures. The cabling machine at TD, which is equipped to fabricate cables with up to 42 strands, will be used for Bi-2212 Rutherford and multi-layer round cables.

Progress on characterizing HTS materials, the engineering current density (J_E) as a function of magnetic field, temperature, field orientation as well as transverse, longitudinal and bending strain/stress are essential inputs to a practical magnet design. HTS tapes just need extensive evaluation of the aforementioned properties to monitor industry progress [6]. Bi-2212 wire has still several challenges to face before deemed suitable for practical use in magnets [7]. This work will be carried out in cooperation with the HTS National Collaboration. To contribute to the technological progress of Bi-2212 wire and at the same time help the HTS National Collaboration, which has limited funding for industry, Fermilab has developed an R&D proposal with Nexans to produce powders using advanced granulate precursors. This proposal may be funded and approved by the MCTF at the end of FY2008.

The development and test of prototype Rutherford and round multistrand cables to be used in the Bi-2212 magnet models aim at reducing degradation of transport properties, and at quantifying the effect of the transverse pressure conveyed to the cable during magnet fabrication and operation. In the React&Wind technique, the degradation due to the bending strain introduced during winding has also to be considered. Short samples of different cables will be designed and fabricated within a range of packing factors to compare results of I_c measurements made on round virgin strands with those made on extracted strands and on cables.

Based on the results of this program, the most useful or promising HTS strands and cables will be selected to be used in the HTS coil program.

References

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